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Technical Report 145

MEASUREMENT OF FROST HEAVING FORCES ON PILES

by

F. E. Crory

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OCTOBER 1965

Conducted for

CORPS OF ENGINEERS, U. S. ARMY

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U.S. ARMY MATERIEL COMMAND

COLD REGIONS RESEARCH & ENGINEERING LABORATORY

HANOVER, NEW HAMPSHIRE

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PREFACE

This is one in a series of U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) reports on studies of frost action on piles in arctic and subarctic areas. These investigations are part of a program of studies being conducted by USA CRREL for the Engineering Division, Directorate of Military Construction, Office,Chief of Engineers. The program is administered by the Civil Engineering Branch of the latter agency. This report describes exploratory tests (1956-1963) conducted at the USA CRREL Alaska Field Station at Fairbanks to measure the force exerted on piling during frost heave. The methods used to measure frost heave forces are presented and the results obtained to date are analyzed.

The initial part of this study (1956-1961) was carried out by the Arctic Construction and Frost Effects Laboratory* of the U. S. Army Engineer Division, New England. Subsequent work has been accomplished under USA CRREL. The investigations were conducted under the direction of Mr. K. A. Linell as program engineer in-charge and Mr. E. F. Lobacz, both of whom contributed substantially to the program. Mr. William Dias was project leader of the initial program (1956-1959). The field installations and observations were performed by personnel from the Alaska Field Station, under the supervision of Mr. F. F. Kitze. The authors gratefully acknowledge the efforts made and the hardships undergone by these field personnel in obtaining daily observations throughout long and cold winters.

The contributions of Professor A. Casagrande of Harvard University, Professor K. Woods of Purdue University, and Dr. P. C. Rutledge of the firm Mueser, Rutledge, Wentworth and Johnson as consultants on this and other programs are also gratefully acknowledged.

Commanding Officer of USA CRREL during the preparation of this report was Colonel Philip G. Krueger and the Technical Director was Mr. W. K. Boyd. Mr. K. A. Linell was Director, USA ACFEL, during the first five years of the study.

USA CRREL is an Army Materiel Command laboratory.

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*Consolidated with the Snow, Ice and Permafrost Research Establishment to form the U. S. Army Cold Regions Research and Engineering Laboratory, 1 February 1961.

CONTENTS

ILLUSTRATIONS

SUMMARY

A program of studies has been conducted at Fairbanks, Alaska, incorporating reaction measuring devices and SR-4 strain gages, to measure the magnitude of heave force on piles and distribution of stresses in piles during seasonal freezing of the silt active layer. This report summarizes the results of frost heave force measurments with the reaction type devices on creosoted timber and steel pipe piles during the period 1956-1959 and during the 1962-1963 freezing season. The heave force measurements, along with air and ground temperatures, are presented and analyzed. The results of the studies using SR-4 strain gages will be presented in a separate report.

MEASUREMENT OF FROST HEAVING FORCES ON PILES

by

F. E. Crory and R. E. Reed

INTRODUCTION

Purpose and scope

In the arctic, subarctic and temperate regions of the world, the upper layers of ground are subjected to seasonal freezing and thawing. During the freezing process the normal moisture in the soil, and that drawn up from greater depths, is converted to ice as crystals, lenses or other forms. The formation of ice lenses during the freezing process, aided slightly by volume expansion of the water in the soil voids, tends to produce an upward movement or heaving of the soil-ice mass. This raising or heaving of the ground surface may vary from nothing in confined well-drained sands and gravels to a foot or more in saturated silts and clays. The magnitude of heaving is dependent upon such factors as the rate of frost penetration, soil type, effective pore size, and moisture conditions.

This report presents the results of part of a program of field measurements of forces acting to cause frost heaving of piles in the frost-susceptible silt of the active layer overlying permafrost at the Alaska Field Station (AFS), Fairbanks, Alaska.* The observations are considered representative of the heave force potential of similar silty soils commonly found throughout the arctic and subarctic regions of the Northern Hemisphere. Since the observed heave forces are a phenomenon caused by seasonal freezing and permafrost acts only to restrict availability of moisture, comparable uplift forces may be assumed to act in non-permafrost regions. Although the study was primarily concerned with frost heaving forces on piles, the results are also applicable to footings, utility poles, and posts subjected to frost action.

Inasmuch as these studies are being continued at present (1965), this should be considered an interim report, which, together with the information to be presented in the companion report on measurements made with SR-4 type electric strain gages, reflects only the present state of knowledge on frost heaving forces on piles.

Background and previous work

Ventilated pile foundations for structures, incorporating an airspace between the floor and ground surface, have for many years been used effectively in permafrost regions where the soil is frost-susceptible and subject to considerable heaving and subsidence during the annual freezing and thawing of the ground. Normally, piles are installed in frozen ground by the use of steam or preformed holes. The most commonly used installation method in Alaska at present is the dry-augered hole, utilizing a soil-water slurry in the annular space surrounding the pile. The natural "cold reserve" of the permafrost, or artificial refrigeration through pipes attached to the perimeter of the piles, is utilized to freezeback the slurry. In recent years, open-ended pipe and structural steel sections have been effectively installed by conventional driving methods. When adequately embedded in the underlying permafrost, piles form a stable foundation, unaffected by the vertical displacements of the freezing and thawing of the active layer.

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*As discussed later, this report does not cover studies in which SR-4 type strain gages were used to measure heave forces. These will be covered in a separate report.

If the piles are not embedded to sufficient depth in the permafrost or complete refreezing is not attained before the ground surface freezes, they may be uplifted by frost action. Although considerable data and evidence of frost heaving of piles are available, no measurements existed at the start of this study on the actual magnitude of the frost force which might act to cause pile uplift. It was thought that if this force were known, this knowledge could be used advantageously in such applications as design of reinforced concrete piles to resist tensile stresses caused by frost heave and design of foundations under heavy structures. Figure 1 shows the heave of a number of test piles installed at the Alaska Field Station in 1952 using steam or wash-bored holes (U. S. Army Corps of Engineers, 1955). Such heaving would, of course, be intolerable in a foundation, particularly if heave were differential between piles.

Various methods of preventing pile heave have been evaluated at the Alaska Field Station and at other Alaskan sites. These include oil-wax-filled sleeves or casing, anchor plates, notches, supplemental lugs (angles and railroads spikes) and backfill treated with chemical additives. The depth of pile embedment in permafrost necessary to resist pile heave has also been closely monitored in all pile investigations at the AFS.

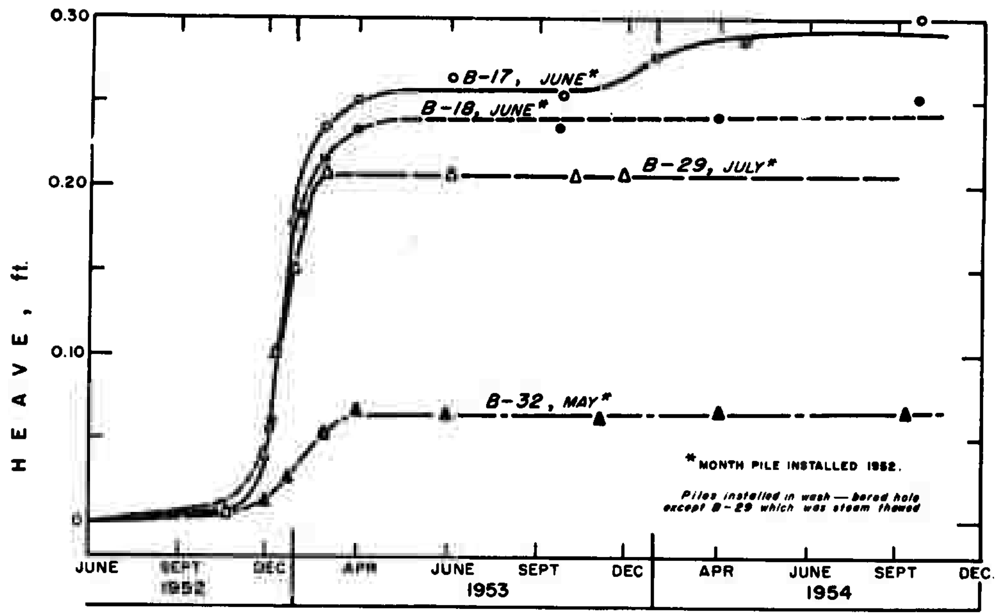


Figure 1. Heave vs time for a number of piles in pile site B.

SITE CONDITIONS

General

The Alaska Field Station is located about 2.5 miles northeast of the city of Fairbanks, Alaska. The terrain at the station is characterized by a comparatively smooth gentle slope to the west, providing good surface drainage except at the lowest elevations. The area is located partly on the lower colluvial slopes of the rock upland of Birch Hill, to the southeast, and partly on the edge of the valley fill.

Fairbanks has a continental climate, conditioned in a large measure by the response of the land mass to variations in solar heat received, and sheltered from maritime influences by various Alaskan mountain ranges. The mean annual temperature is +25.8F, with extremes of +93F and -66F. During June, July and August, when the sun is above the horizon for over three-fourths of the day and at its zenith, the average maximum daily temperatures reach the lower seventies. Conversely, from November to March, when the sunshine duration ranges from 10 to less than 4 hours per day and the sun is at a relatively small angle above the horizontal, temperatures normally fall below 0F. During December and January maximum temperatures are usually below 0F.

On the average, the amount of cloudiness is low, particularly between February and April. Prevailing winds are from the southwest in June and July and from the north or northeast the remainder of the year. Wind speeds are particularly low during winter months. Precipitation normally follows a fairly regular pattern and the average annual precipitation of about 12 in. must be classed as relatively light. Precipitation increases through the summer months to a maximum in August. A noticeable decline in precipitation occurs from September through December. However, snowfall begins to increase toward the end of December and reaches a maximum in January. April has the lowest monthly precipitation and the greatest percentage of sunshine.

The average last day of freezing temperatures in the spring is 21 May, and the average first occurrence of freezing temperatures in the fall is 30 August. The mean freezing and thawing indexes are about 5300 and 3200 degree-days Fahrenheit, respectively.

Pile test areas

The test piles for the investigations reported herein were installed in two test areas, designated pile sites B and C (Fig. 2). Pile site B, an area approximately 100 by 200 ft, was cleared of all trees, brush and surface organic material in the spring of 1950. A total of 32 test piles were installed in this area in the summer of 1952 (U. S. Army Corps of Engineers, 1955; Linell, 1955). The test piles, of steel pipe, timber, steel I-beams, and precast reinforced concrete, were installed in steam-thawed and wash-bored holes. Piles were installed directly in the steam-thawed holes while the piles in wash-bored holes were backfilled with a silt-water slurry, after removal of drill water. The piles were tested in both extraction and load settlement.

Pile site C, just east of the runway test section, is an area approximately 200 by 200 ft in which 97 test piles were installed in 1957 (Crory, in prep). Additional test piles were installed at the site in subsequent years. All piles in this area were installed in dry-augered holes and backfilled with silt-water or clay-water slurries, water, or dry sand. Before hand clearing in the winter of 1956-1957, pile site C had a dense growth of white and black spruce, predominantly the latter. Many of the white spruce attained heights of 30 to 50 ft, while the majority of the black spruce stood in clusters to heights of only 6 to 12 ft. As in other wooded areas at the station, the ground surface in pile site C consisted of a thick mantle of moss cover, with low bush cranberries, blueberries, and other low plant growth. The moss is

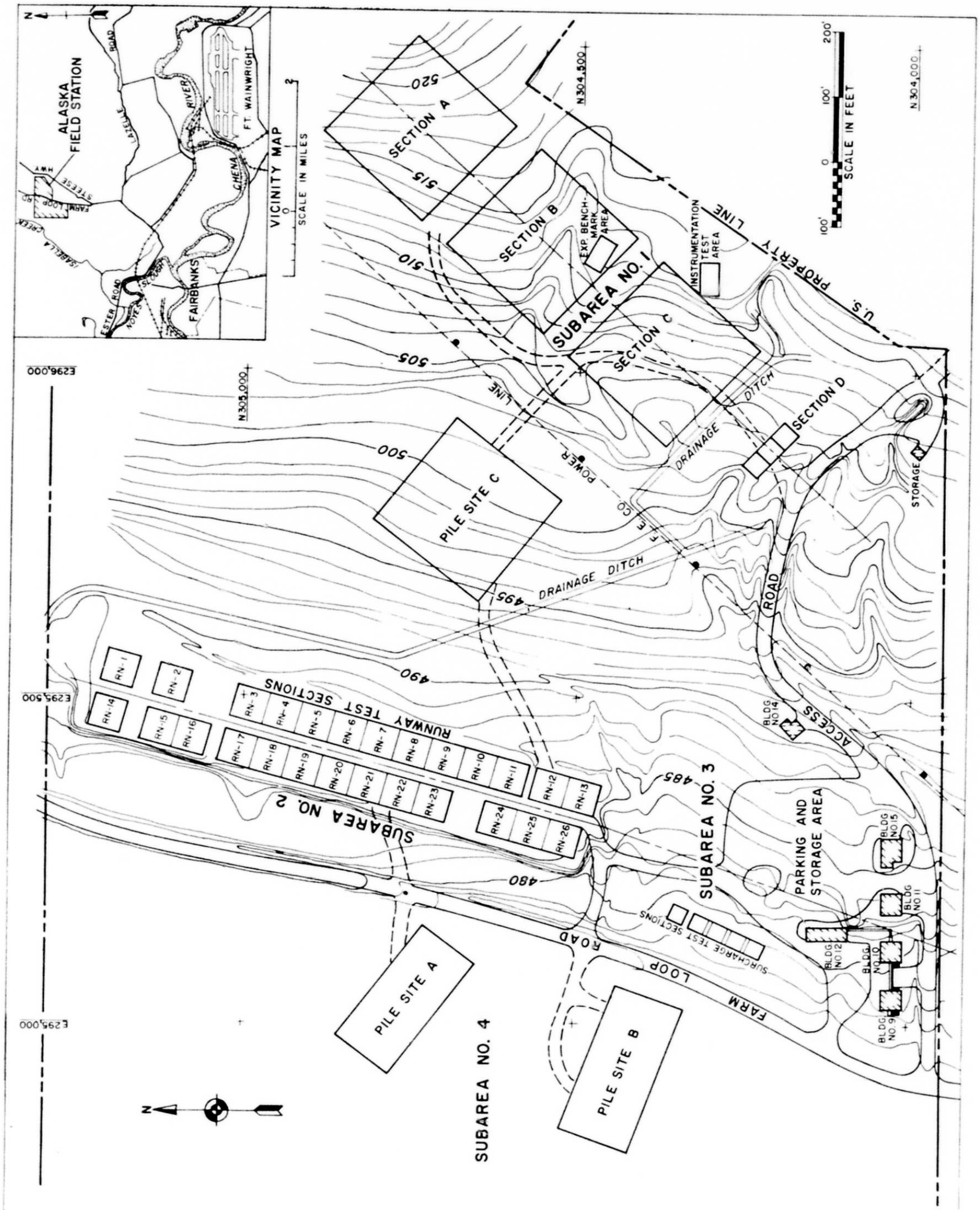
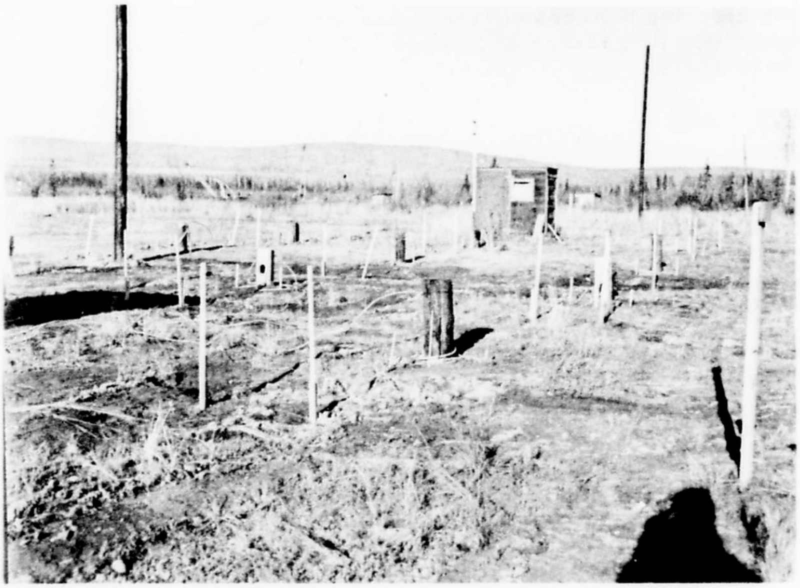


Figure 2. Plan of Alaska Field Station.



a. General view of pile site B - October 1953.

b. General view of pile site C - May 1957.

Figure 3. Photographs of pile sites B and C.

underlain by a 4- to 9-in. layer of black organic material. The lush moss cover, undisturbed in clearing the area of trees, has since been replaced by an ever increasing density of wild grasses and weeds. Photographs of pile sites B and C are shown in Figure 3.

Soil conditions

Although the soil conditions do not vary appreciably at the field station, except with respect to ice and organic content, it was considered essential to know the soil conditions at each of the heave-test piles for analysis of heave data. Accordingly, samples were obtained usually at the exact location of the test piles, with sampling extending through the suprapermafrost* and into the permafrost for a few feet. In most cases, the exploration hole above the permafrost table was enlarged, as described later, to receive the test piles. Other explorations were made adjacent to the installed piles. Boring logs and soil data for each of the three tests in pile site B and the single test in pile site C, including descriptions of the soils, in accordance with the ACFEL method of describing and classifying frozen soils (U. S. Army Corps of Engineers, 1952), water content, and dry unit weights are shown in Figures 4 and 5.

In general, the soil at both sites consists of tan silts near the surface and gray silts at depths exceeding 4.5 ft, with tan and gray layers at intermediate depths. The silt at each test location contains layers of peat, normally less than 3 in. thick. Organic silt, often black, was encountered in all explorations both as distinct layers and as sporadic small inclusions. Figure 6 shows a typical gradation curve for the tan silts at both test sites. All soils were found to be saturated except very near the surface (0.0 - 0.5 ft) and in the September 1957 exploration conducted in site B (Fig. 4b). The effects of the very dry summer of 1957 on the results of the 1957-1958 winter tests are discussed later.

The organic and inorganic silts with peat layers extend to depths of 75 to 125 ft at the station. Sands and gravels are encountered at depths below 75 ft and extend to schist bedrock at about 250 ft. The top of permafrost at the station is normally 2 to 13 ft deep, depending upon the surface cover. The average depth of suprapermafrost in the two pile sites, 3 to 4 years after clearing, was 4 to 5 ft. The depth to the bottom of the permafrost, as disclosed in water well drilling at the station, was found to vary between 102 and 178 ft. Artesian water, high in iron content, was found beneath the permafrost in the sands and gravels.

TEST INSTALLATION

General

The investigations reported herein were conducted as follows: short sections of piling were installed through the suprapermafrost to the top of permafrost and the heave forces generated during the winter were measured by means of proving rings installed between the test pile and a reaction device. The reaction methods have varied for each installation as discussed subsequently.

Each test installation included, in addition to the restrained test pile, an identically installed unrestrained (or dummy) pile, which was allowed to heave upward with the ground. To monitor the vertical movement of these piles, both were instrumented with extensometer-type dial gages mounted on stable instrumentation beams.

To record ground temperatures and advance of freeze and thaw through the seasonal thaw zone, three thermocouple assemblies of 18 gage copper-constantan

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*The entire layer of ground above the permafrost table.

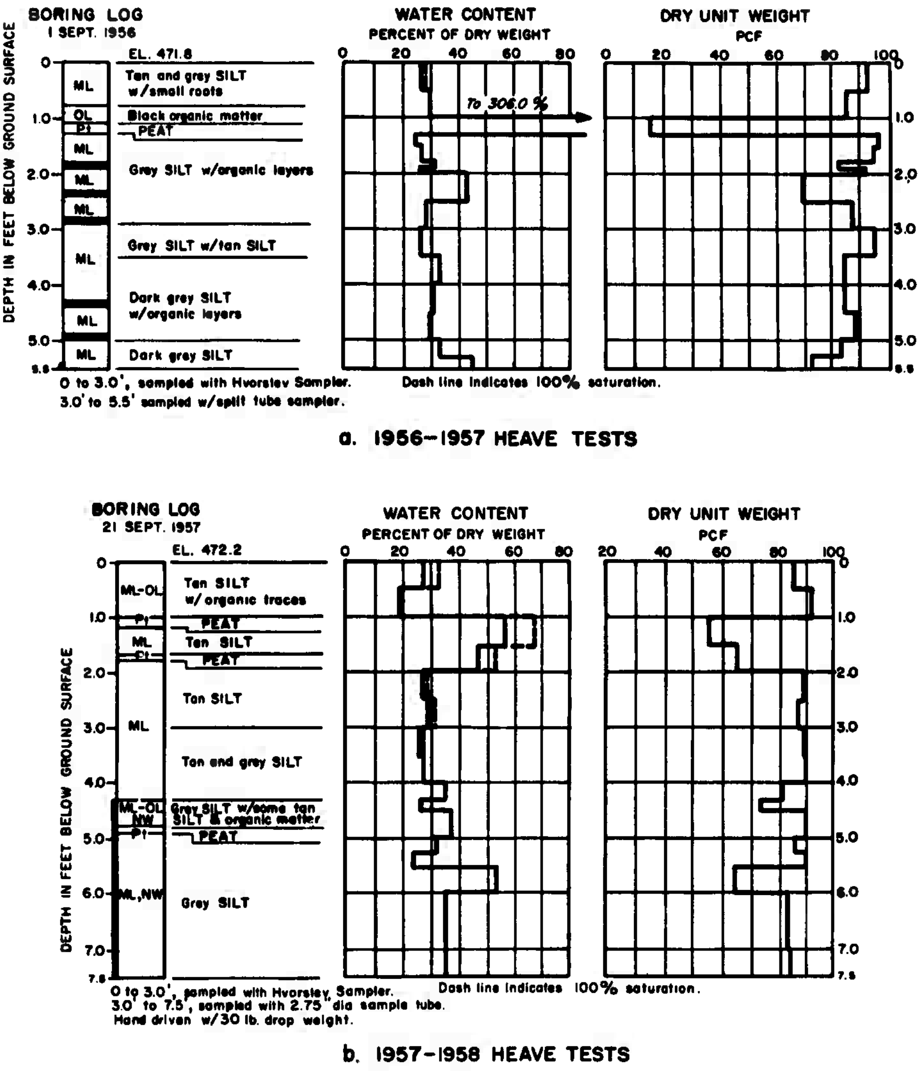

Figure 4. Boring logs and soil data, 1956-57 and 1957-58 tests.

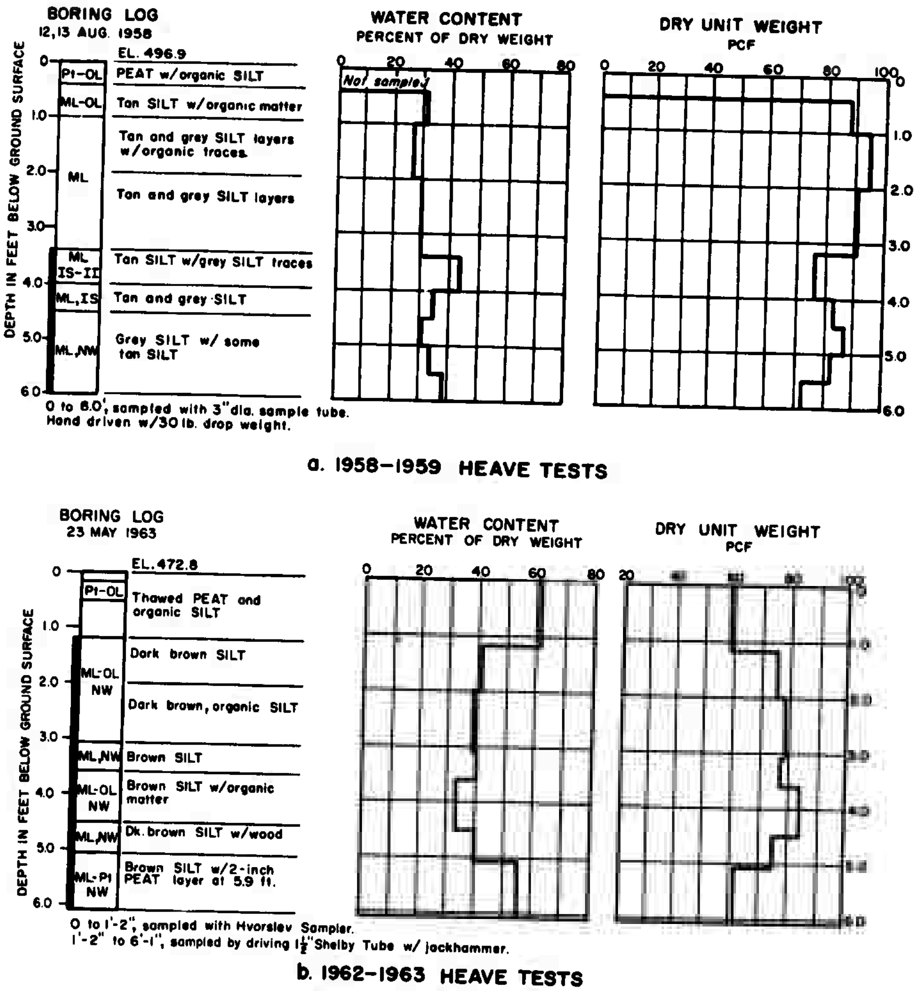

Figure 5. Boring logs and soil data, 1958-59 and 1962-63 tests.

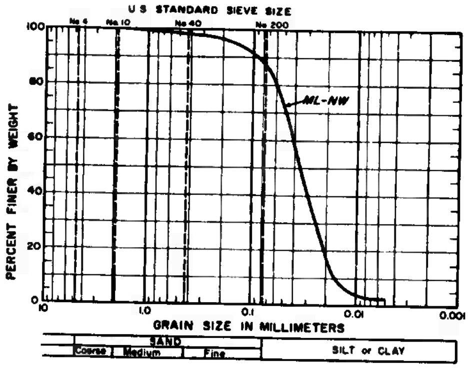

Figure 6. Typical gradation curve, Fairbanks silt.

wire were installed in each test installation. Thermocouple assemblies were installed approximately 1 in. from each of the test and dummy piles; one was also installed in the natural ground midway between the two piles. The lengths of the assemblies varied, but in general the thermocouples were spaced at 3-in. intervals from the ground surface to the top of permafrost and at greater intervals below the permafrost table. Temperatures were recorded with a portable precision millivolt potentiometer having an ice bath reference junction.

Detailed descriptions of each test and the instrumentation used are given in the following sections. Air and ground temperatures, vertical movement of test and dummy piles, and the heave force generated in each test are presented in the form of composite time plots (Figures 16 through 20).

Studies of frost heaving of piles equipped with SR-4 type electric strain gages have also been conducted in pile sites B and C. Some of these piles were equipped with gages only in the seasonally thawed layer (one of these is the test pile in the 1962-1963 tests); others were instrumented in both the seasonally thawed layer and for the full length of the pile in permafrost. The strain gages reflect both the intensity and distribution of the heaving stresses and the reactionary stresses produced in the underlying permafrost. Because of the scope and complexity of these studies, they are not included in this report, but are covered in a separate report (Reed, in preparation).

1956-1957 test installation

The first heave-force measurement installation was made in early September 1956, in pile site B. Figure 7 shows plan and elevation of heave test pile, dummy pile, and instrumentation support piles.

The heave test and dummy piles were sections of 8-in. standard steel pipe, 6.0 and 6.3 ft long respectively. They were installed open end down in 12 in. diam holes, manually excavated with a posthole auger to a depth of 5.4 ft, which was the depth from the ground surface to the top of permafrost at the time of installation. The annular space surrounding the piles was backfilled with a thick silt-water slurry and vibrated with a concrete vibrator to prevent the formation of any large voids. Water content samples of the slurry were not obtained. The test pile was located midway between piles designated as B-18 and B-19, which were used as support piles for the reaction beam. Both the test and dummy piles were capped at the top with a steel plate.

The support piles, B-18 and B-19, also 8-in. pipe, were installed open end down in 12 in. diam wash-bored holes in June 1952. Pile B-18 had an overall embedment of approximately 19.0 ft below ground surface and B-19 had an embedment of approximately 23.0 ft. Both piles had been tested in quick extraction in November 1954, with B-18 failing at an ultimate load of 140 kips and B-19 failing at 200 kips. Both piles remained unloaded from November 1954 until September 1956.

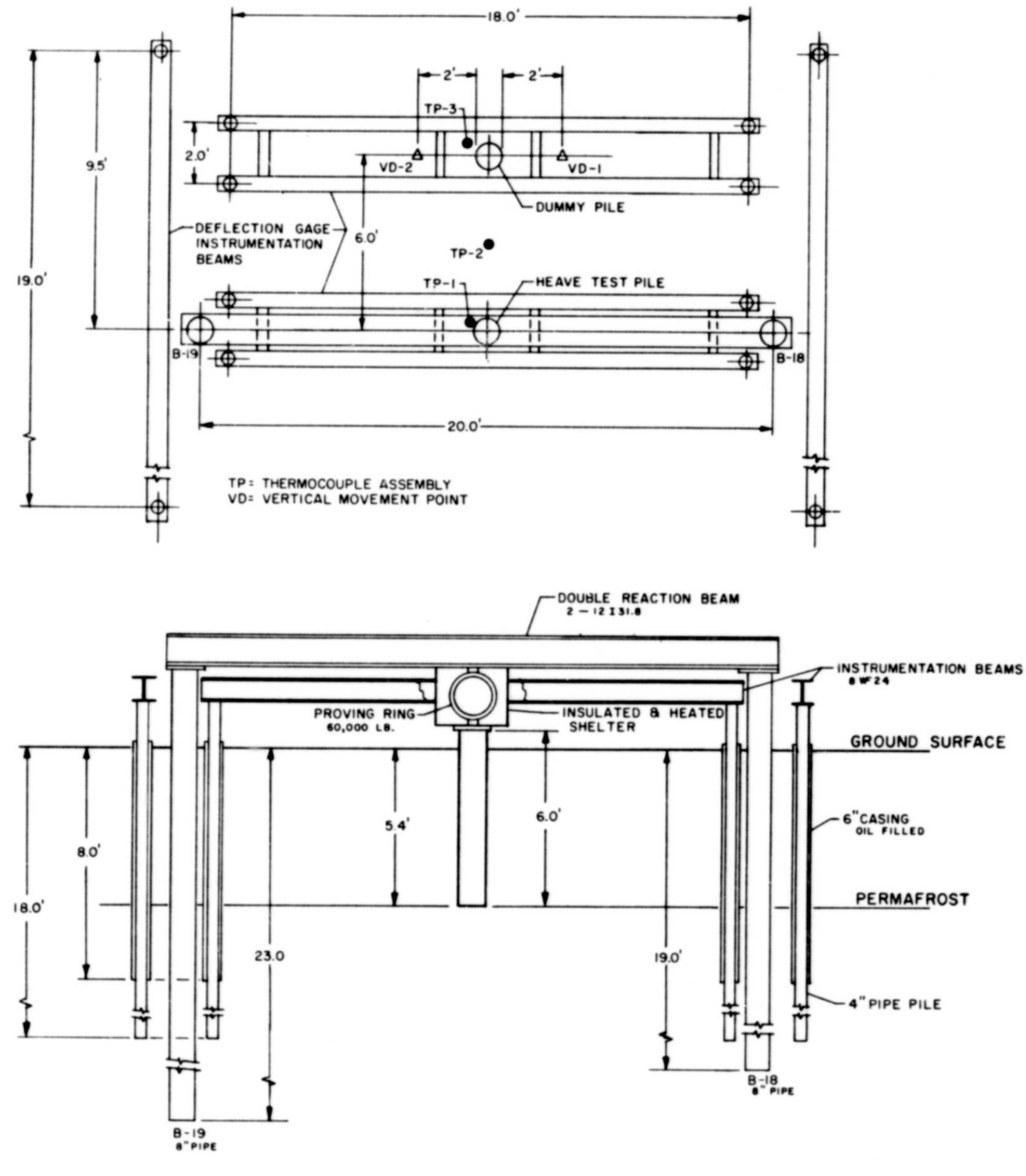

Figure 7. Plan and elevation view of 1956-57 heave test installation. Proving ring housed in wooden box insulated with foamglas and heated with light bulbs.

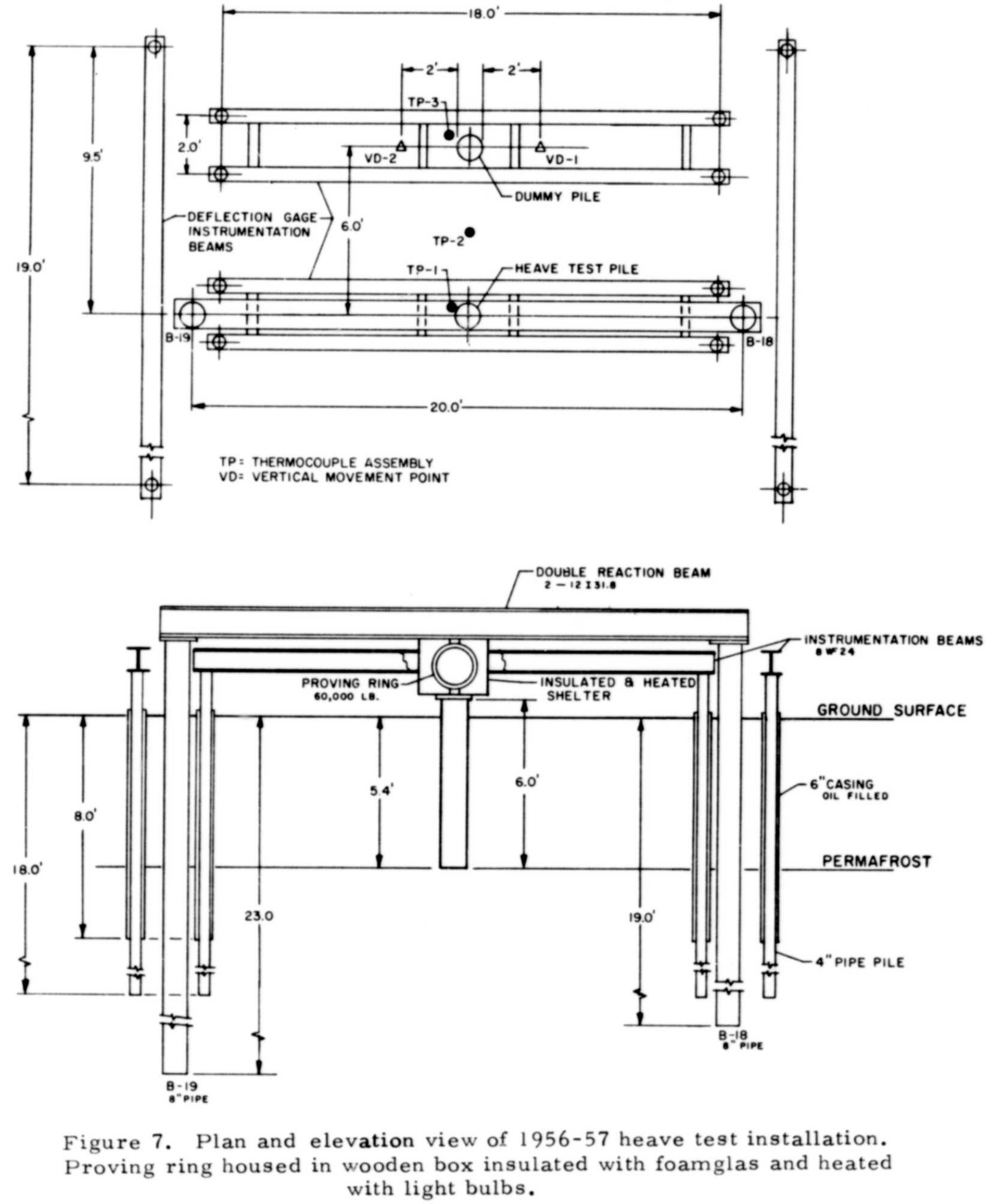

Figure 7. Plan and elevation view of 1956-57 heave test installation. Proving ring housed in wooden box insulated with foamglas and heated with light bulbs.

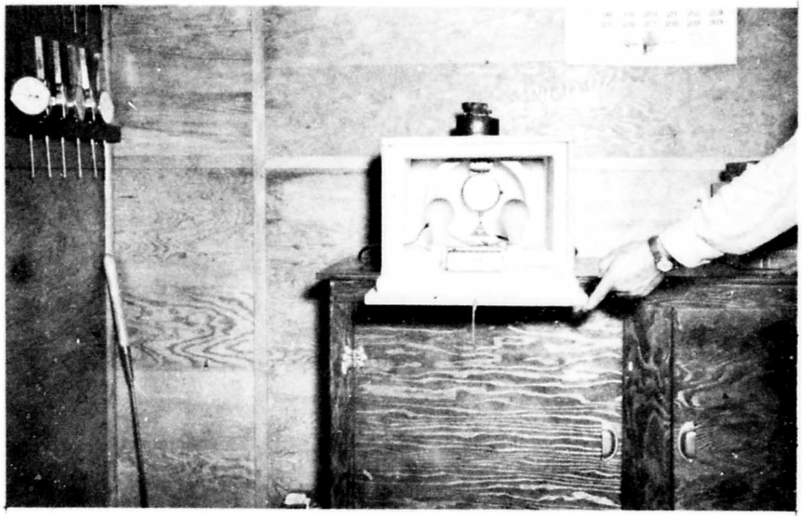

Figure 9. View of insulated proving ring shelter.

Thermocouple assemblies were installed approximately 1 in. from the test pile and dummy pile and also in the natural ground midway between the two piles. Thermocouples were located at 3-in. intervals from the ground surface to 5.25 ft and at 6.0 and 7.0 ft.

The entire test area was protected by a wood frame shelter to facilitate maximum frost penetration by preventing the accumulation of snow and to shield the instrumentation from sunlight, which though weak could cause spurious deflection readings by differential heating and deflection of the metal members.

1957-1958 test installation

Because of the movement of the support piles in the 1956-1957 test, it was believed that the test results did not reflect the true magnitude of the heave force and that further investigations were required. In the fall of 1957 another heave force measurement installation was made in pile site B approximately 7 ft from the 1956-1957 installation. At the time of the installation (September 1957) the permafrost table was about 1 ft higher than in September 1956. This aggrading of the permafrost was attributed to the shading and cooling effect of the shelter erected over the site the previous winter.

This installation also consisted of a test pile (restrained) and a dummy pile (unrestrained) of 8-in. standard steel pile installed open-end down in 12-in. manually excavated holes, with the bottoms of the piles resting on the top of permafrost at a depth of 4.3 ft. The annular space was backfilled with a thick silt-water slurry. The average of four samples taken of the slurry indicated a water content of 42%.

In an attempt to eliminate the stability problems encountered in the 1956-1957 tests, a different reaction method was used. A load platform (Fig. 10) was erected over the heave test pile to serve as a reaction for the proving ring. The platform support piles, S-1 through S-4, consisted of extra heavy galvanized pipe, $6\frac{5}{8}$ in. O. D. with base plates 10 in. in diameter and $\frac{7}{8}$ in. thick welded to the bottom of each pile. These piles were installed to 17 ft below the ground surface in 12 in. diam dry augered holes and backfilled with a vibrated silt-water slurry.

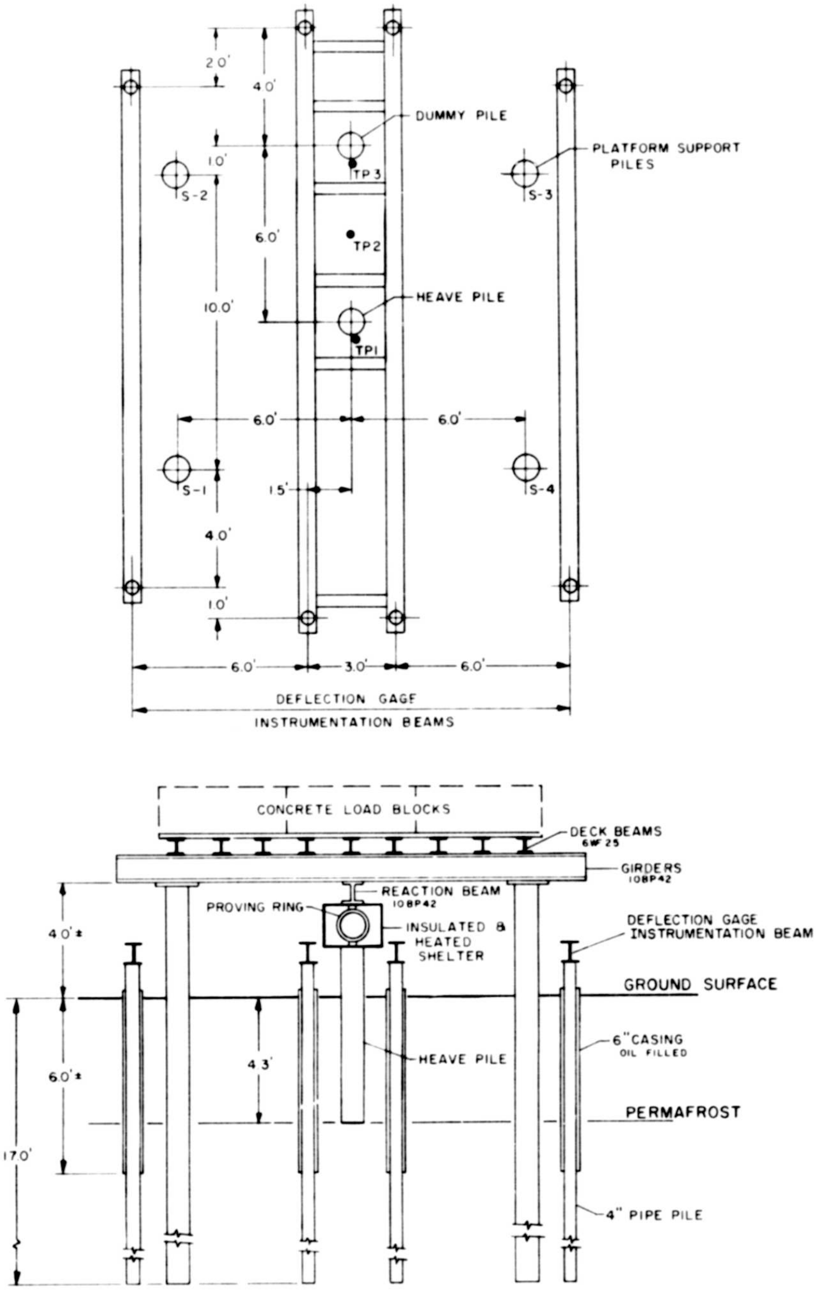

Figure 10. Plan and elevation view of 1957-58 heave test installation.

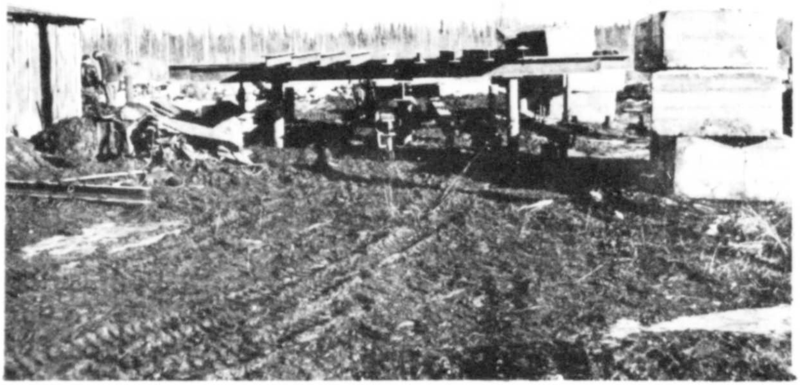

Figure 11. General view of load platform, 1957-1958 heave test.

The load platform, 12 x 10 ft, was constructed of 10 BP42 girders welded to plates on top of the support piles. The floor beams were 6 WF25 beams placed 18 in. O. C. and spot welded to the girders. A 10 BP42 beam was welded to the bottom of the girders to serve as a reaction beam. Safety cribbing was placed beneath each end of the reaction beam. The computed weight of the load platform was 8000 lb. An additional load of 70,000 lb (5000-lb concrete blocks) was added to the platform. Figure 11 is a photograph of the installation showing the load platform and concrete load blocks.

The heave force measurement and ground temperature instrumentation were the same as in the previous test. Instrumentation beams were installed by the same method as in the 1956-1957 test to 17 ft below ground surface. Three dial gages, graduated to 0.001 in., were installed 120 deg apart on the test and dummy piles to observe the vertical movement and two gages were installed on each of the four platform support piles. All of the dial gages were heated by an electric light bulb with an aluminum foil hood to assure proper functioning during extreme cold weather.

The area was sheltered by the load platform supplemented by canvas extending from the four sides of the platform. The canvas was supported well off the ground to allow free circulation of air under the platform.

1958-1959 test installation

The 1958-1959 test installation was made to study the intensity of heave force generated on creosoted timber piles. A test pile (restrained) and a dummy pile (unrestrained) were installed in the southern corner of pile site C in the summer of 1958. The piles were sections of surplus piling from pile site C which had thick coal-tar creosoted surfaces. The test pile was 6.0 ft in overall length, with tip and butt diameters of 13.4 and 14.4 in., respectively. The dummy pile was 6.5 ft long, with corresponding diameters of 13.2 and 15 in. Both piles were installed tip down in holes manually excavated through the suprapermafrost to the top of permafrost. The annular space between the pile and hole was filled with a thick slurry made from the excavated soil. Water content of the slurry at the test pile was 44%, that used at the dummy pile averaged 45%. The actual embedments of the test and dummy piles were 3.5 and 3.37 ft, respectively, below the ground surface.

The reaction to the heave force was provided by a load platform similar to the 1957-1958 installation. The platform was supported by four 8-in. standard steel pipe piles installed in dry-augered holes to a depth of about 22.0 ft. Each platform support pile was cased through the active layer with 12-in. casing filled with oil-wax to eliminate frost heave forces. The location of the piles and the details of the load platform are shown in Figure 12. The instrumentation beams were supported on 4-in. pipe driven to approximately 15 ft below ground surface with the top 6 ft encased in 8-in. pipe filled with oil-wax. The complete installation is shown in Figure 13.

The vertical movement instrumentation on the test and dummy piles was identical to the instrumentation used in previous tests. An additional dial gage was placed on each platform support pile to check platform stability. All of the dial gages were hooded with aluminum foil and heated by electric light bulbs to ensure proper functioning during cold weather. Thermocouple assemblies in polyethylene tubing were installed approximately 1 in. from the heave test and dummy piles and in the natural ground midway between the two piles. Thermocouples were spaced at 6-in. intervals from 0.0 to 6.0 ft. The 60,000-lb proving ring was installed and protected from the weather as in the previous tests.

1962-1963 test installation

In the summer of 1962, two heave force test piles were installed approximately 75 ft southeast of the two earlier tests in pile site B. The installation included heave test and dummy piles of both creosoted timber and 8-in. steel pipe (Fig. 14a).

In this installation, unlike the previous tests, the reaction to the heave force was provided by anchor piles installed directly below the test piles (Fig. 14b). The anchor piles, 25 ft in length, were installed in 18 in. diam dry-augered holes so that the tops of piles were 6.5 ft below ground surface. The annular space was filled with a thick silt-water slurry, thoroughly vibrated in place. At the time of installation, seasonal thaw extended only to a depth of 3.0 ft and a probable depth to permafrost of 6.5 ft was assumed, based on previous thermocouple readings taken in pile site B. The anchor for the pipe-pile installation was made from 8 in. diam steel pipe, and the timber pile anchor was made from a section of 6 WF25 steel column. Four 1 in. diam rods extended through the full lengths of test piles to transfer the force to the anchor piles. As shown in Figure 14b, the rods were welded to the anchor pile in the timber pile installation and were held by nuts bearing on a $1\frac{1}{2}$-in. plate welded to the inside of the anchor pile in the pipe pile installation. The proving rings were placed at the tops of the assemblies between two $1\frac{1}{2}$ in. thick plates, with the top plates being restrained by nuts on the 1 in. diam rods. The joint between the 8-in. pipe test and anchor pile was sealed with a rubber gasket made from a truck tire tube to prevent the entrance of ground water or slurry.

The timber test and dummy pile sections were cut from the creosote-treated butts of power poles. Both pile sections were 10.0 ft in length and the average diameters of the heave and dummy piles were 14.03 and 12.13 in., respectively. To provide for the passage of the 1 in. diam rods through the timber test pile, longitudinal slices were cut along two sides of the pile and four $1\frac{1}{2}$-in. slots were then cut out of the pile. The two sections sliced from the pile were then replaced in their original positions and refastened to the pile with nails, as shown in the end view of the piles in Figure 15. The test pile was installed 6.5 ft in the ground, and the bottom of the dummy pile was installed 6.25 ft below the ground surface.

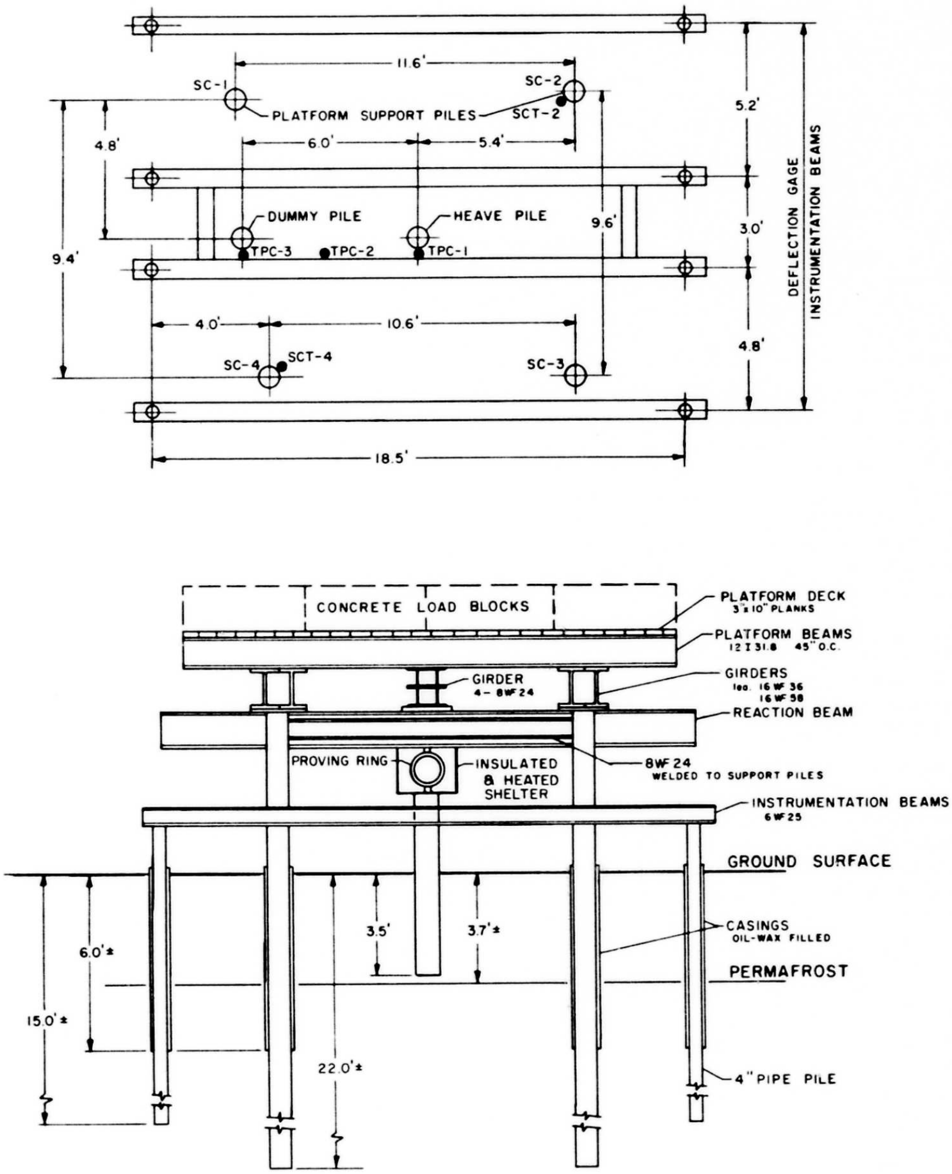

Figure 12. Plan and elevation view of 1958-59 heave test installation.

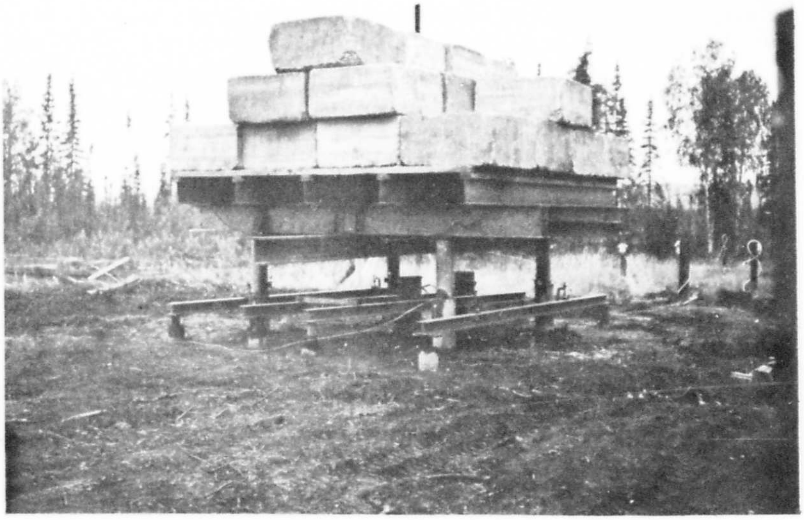

Figure 13. General view of test installation, 1958-1959 heave test.

The dummy and test pipe piles, 10.0 and 8.9 ft long, respectively, were installed in a similar manner. Silt-water slurry prepared from the excavated auger cuttings was used to backfill the annular space around each pile; water contents for the pipe test and dummy piles and for the timber test and dummy piles were 51, 55, 51 and 52%, respectively.

Beams to support the vertical movement instrumentation (Fig. 14a) were supported by 4.5 in. diam pipe piles driven to approximately 11 ft below ground surface with 7 in. diam pipe used as casing through the active layer. The annular space between casing and pile was filled with oil. Three dial gages, heated by 100-w light bulbs, were installed on each pile to measure the vertical movement.

Thermocouple assemblies were fastened with tape to each test and dummy pile, with thermocouples spaced at 6-in. intervals from the ground surface to a depth of 6.0 ft. Additional assemblies were fastened to and installed with the two anchor piles. Thermocouples were located at 6.0, 8.0, 10.0, 15.0, 20.0 25.0 and 31.0 ft.

The original 60,000-lb capacity proving ring used in the previous tests was installed on the pipe pile and a new 50,000-lb proving ring was installed on the timber pile, as shown in Figure 14. Both rings were protected in insulated shelters and heated as in earlier tests.

TEST PROCEDURE AND RESULTS

Ground and air temperatures

The observational procedures for the 4 years of testing covered in this report were essentially the same. In each year all of the thermocouple assemblies were observed two or three times weekly from early fall until the following June. The ground temperature isotherms for each test, based on temperature observations at the heave test piles, are plotted on Figures 16-20, which are composite plots of the results for each test. The depth to permafrost for the first three tests was between 4 and 6 ft and penetration of the 32F isotherm to the bottom of the thawed suprapermafrost had occurred by early to late December. In the 1962-1963 tests, the depth to permafrost was about 6.5 ft and the 32F isotherm did not penetrate to that depth until mid-February at the pipe pile and late February around the timber pile. This slight difference can be attributed to the circulation of the colder air to the bottom of the pipe pile by the natural convection of air within the closed pipe.

Daily air temperatures were observed and are plotted on Figures 16-20. Mean daily temperatures normally dropped below 32F between the last week of September and the middle of October and remained generally below 32F until mid-April. Temperatures fluctuated greatly during the winter, with the lowest temperatures (down to the -45F range in the coldest years). occurring in December and January. During the month of January 1963, air temperatures were unusually high, the average temperature being the warmest for January in 26 years for the Fairbanks area.

Vertical movement

As mentioned previously, each test and dummy pile was instrumented with dial gages to measure vertical movement during the winter heaving season. In the 1956-1957 test, vertical movement points were also established to observe the heave of the natural ground surface within 6 ft radius around the pile. The data shown in Figure 16, the average heave of VD-1 and VD-2, indicated that the dummy pile movement was essentially the same as the average ground surface movement until the frost had reached the top of permafrost. In all subsequent tests the vertical movement of the dummy pile was used as an indicator of the relative magnitude of ground surface heave.

In all of the heave force tests, vertical movement observations on the test and dummy piles were made two to three times each day from the start of the freezing season until the following spring. As shown in Figures 16 through 20, the vertical movement of the piles increased as the 32F temperature penetrated the suprapermafrost and decreased or ceased after complete frost penetration of the permafrost. Cumulative heave of the dummy piles was usually between 3.0 and 4.0 in. except for the dummy piles of the 1957-1958 test. Movement of test piles, restrained by the proving rings and reaction devices, was normally 0.5 in. or less, except in the 1956-1957 test, when failure of the support piles and deflection of the reaction beams allowed the test pile to heave approximately 3 in. during the freezing season.

During the 1957-1958 test, vertical movement of the unrestrained dummy pile (Fig. 17) was well below the expected magnitude. This is attributed to the fact that the summer of 1957 was unusually dry and the water necessary to produce the normal heave was not available. The water content of samples obtained just prior to the freezing season, in the first 2 ft below the ground surface, was well below 100% saturation (Fig. 4b).

Frost heave force

Proving ring readings were made at approximately the same time each morning and afternoon from the start of the freezing season until late in the spring. The daily average heave force recorded is plotted at the bottom of Figures 16 through 20. The heave force generally lagged behind ground freezing, starting to increase after the 32F isotherm had penetrated 6 to 12 in. into the ground. The force increased to a maximum when the 32F isotherm had penetrated 80 to 100% of the seasonally thawed layer and then either decreased during the remainder of the winter or fluctuated with air (ground) temperatures.

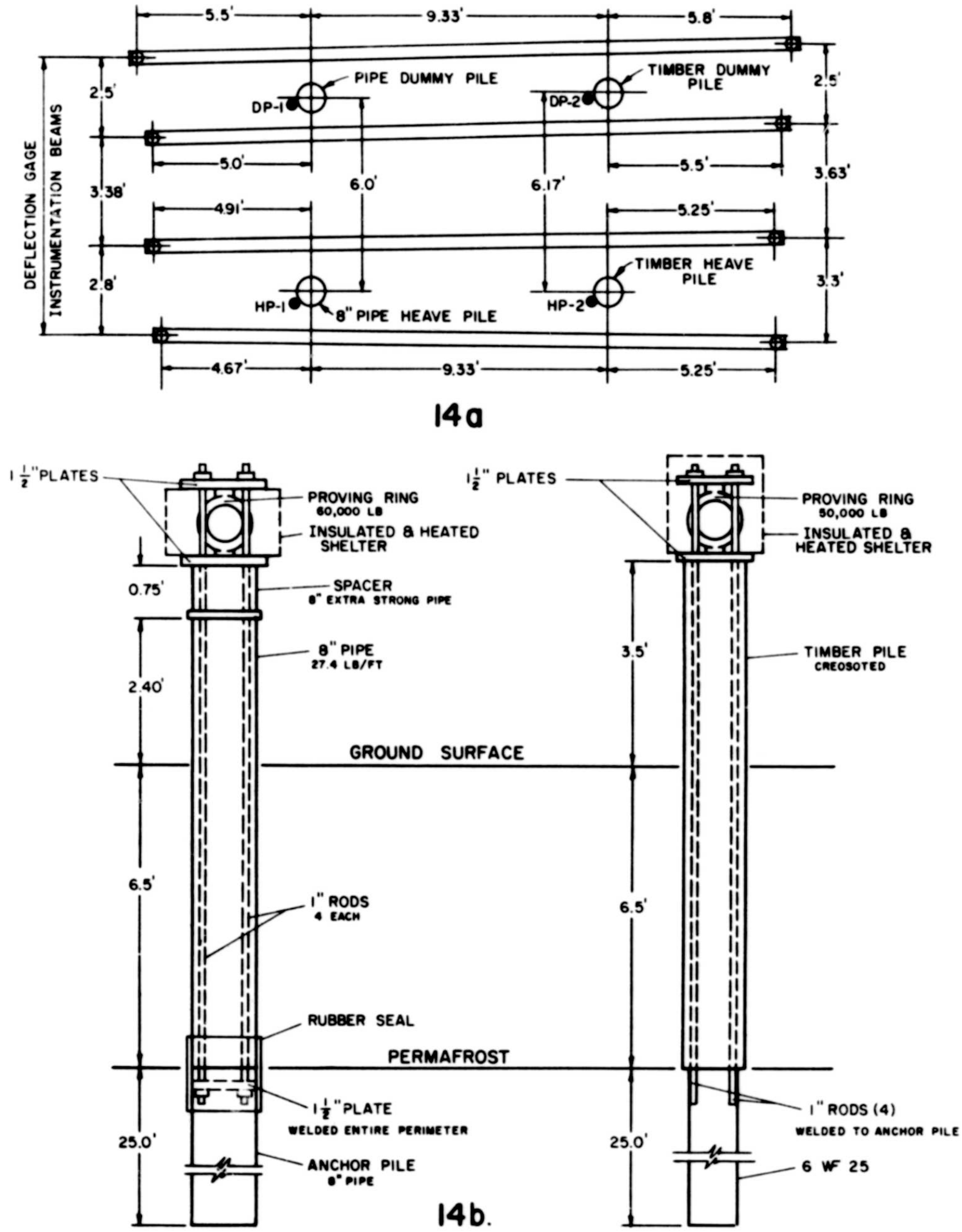

Figure 14. Plan and elevation view of 1962-63 heave test installation.

Figure 15. End view of timber test pile - 1962-1963 test.

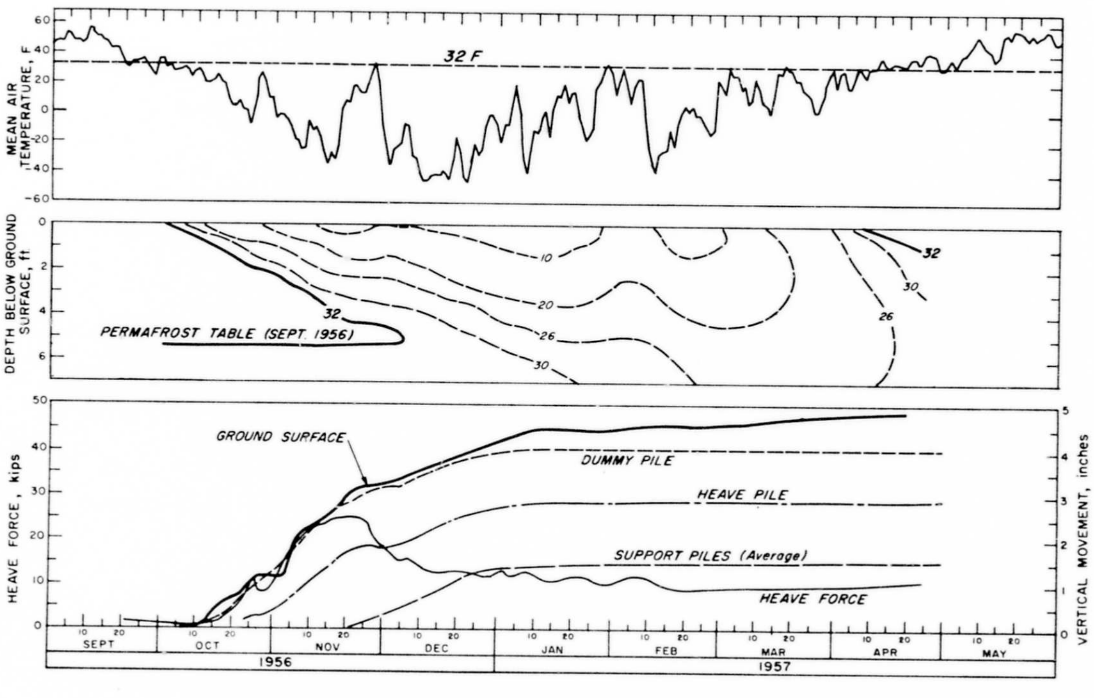

Figure 16. Test observations, 1956-1957 test, 8-in. steel pipe pile.

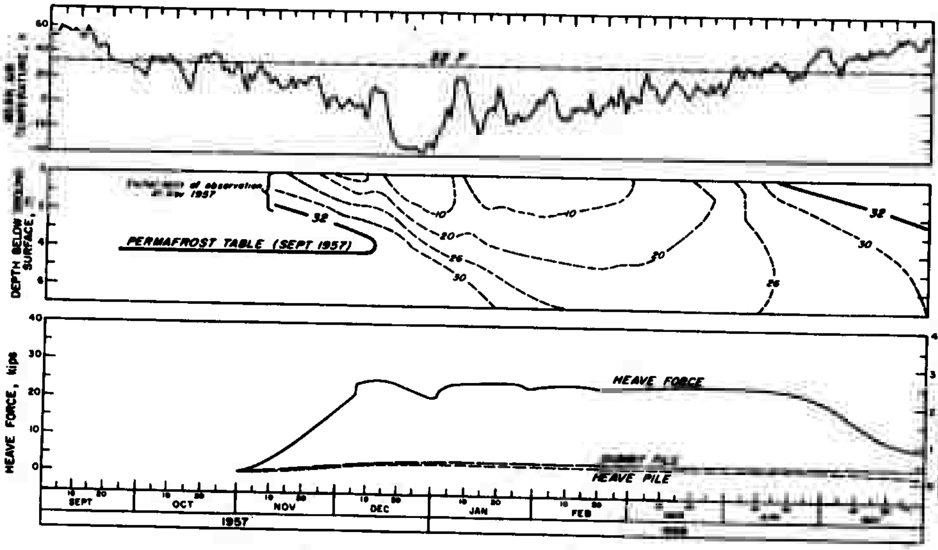

Figure 17. Test observations, 1957-1958, 8-in. steel pipe pile.

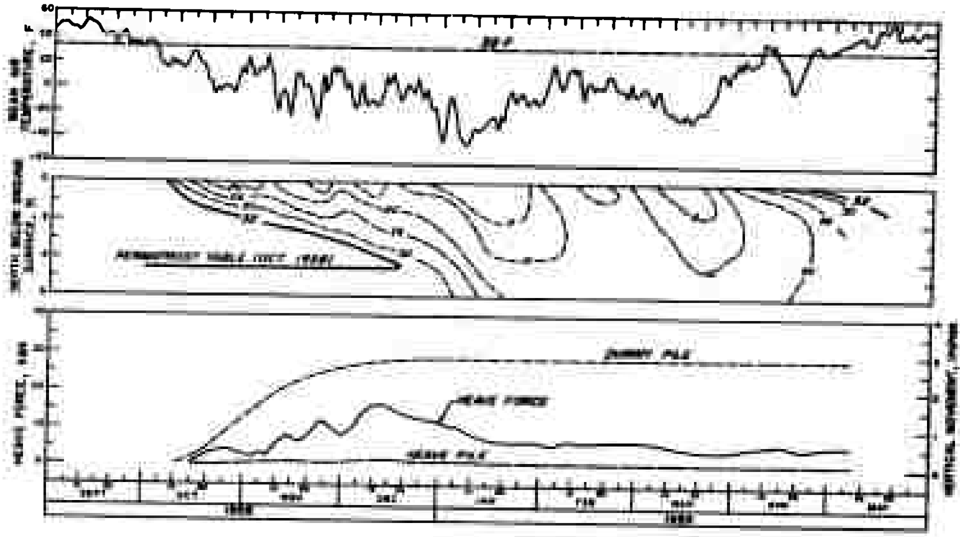

Figure 18. Test observations, 1958-1959. Creosoted timber pile, average diameter 13.8 in.

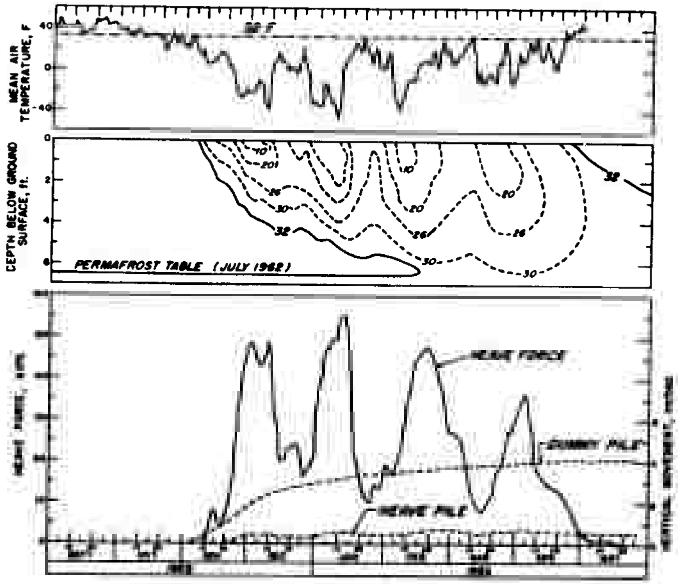

Figure 19. Test observations, 1962-1963, 8-in. steel pipe pile.

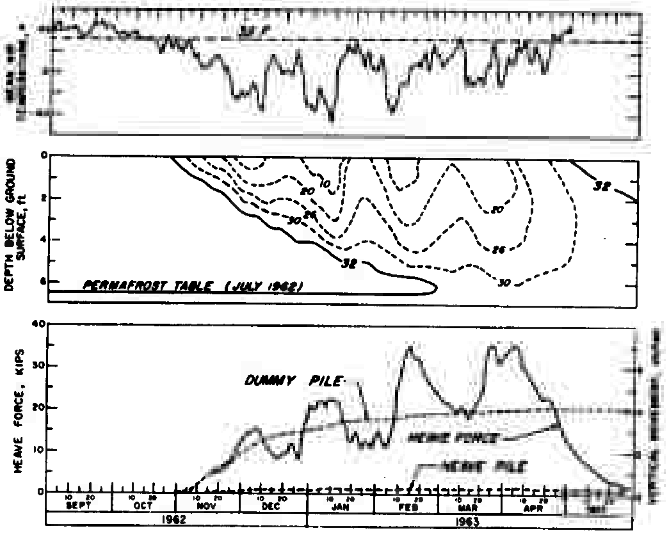

Figure 20. Test observations, 1962-1963. Creosoted timber pile, average diameter: test pile 14 in., dummy pile 12 in.

DISCUSSION OF RESULTS

Frost penetration and pile heave

The results indicate a slight lag between the penetration of the 32F isotherm and the start of dummy pile heave. This lag is attributed to the freezing point depression, the weakness of the adfreeze bond and the frictional resistance of the unfrozen soil to the pile beneath the advancing frost front. Penetration of the 32F temperature usually reached a depth of 3 to 6 in. before measurable heave occurred.

Heaving of the dummy piles continued throughout the freezing of the seasonal thaw layer, attaining a maximum heave of between 3 and 4 in., except for the dry 1957-1958 season. Earlier studies in the Military Construction Investigation program (U. S. Army Corps of Engineers, 1954) had shown that moisture is very rapidly reduced in the lower part of the seasonal thaw zone as frost penetrates downward from the surface in the fall. Vialov and Egorov (1958) noted that, in permafrost areas having a shallow active layer, heaving ended before the freezing of the soil had been completed, and, in areas of deep active layer, the heaving continued, at a diminishing rate, throughout the freezing season. In the first three tests (1956-1957, 1957-1958, and 1958-1959) essentially all heave of the dummy pile had occurred by the time complete freezeback of the active layer had occurred.

In the 1962-1963 tests (Fig. 19, 20) gradual heave of both dummy piles continued throughout the winter season until surface thawing started in the spring. This continued heaving is attributed to the migration of water from the surrounding soil throughout the winter to sustain the formation of ice lenses. The area surrounding the tests had an undisturbed snow cover in contrast to the sheltered area at the test piles and would have had a shallower frost penetration. The assumption that the permafrost table was at the 6.5-ft depth was based on ground temperature observations. The penetration of the 25, 20 and 10F isotherms in the previous tests to the bottom of the seasonal thaw zone was at no time duplicated in the 1962-1963 tests. The frost penetration in the 1962-1963 tests was very much like that experienced in non-permafrost areas, or in areas having a residual thaw layer (Crory, 1960). Temperatures observed on the anchor piles beneath the test piles throughout the winter indicated that the temperatures from 6.0 to 11.0 ft below the ground surface were between 31.5 and 32.0F. At these temperatures, a portion of the soil moisture may have remained unfrozen and the soil (slurry) immediately around the pile between these depths may have indeed never frozen back completely.

Irrespective of the depth of the active layer, it was found that the rate of frost heaving at the three test sites was similar. The maximum rate of heave occurred during the penetration of frost between the 1.5 and 2.5 ft depth for all of the tests (Fig. 21). The variations in the top 2.0 ft, as shown in Figure 21, are attributed to differences in temperatures and water availability during the various winters. Below these depths, the rate of heave decreased sharply. Heave data (Aitken, 1963) obtained in conjunction with another study at AFS, having a deep active layer (10.0 to 11.0 ft), exhibited a similar relationship of heave to frost penetration as shown in Figure 21.

Heave force

Because of yielding of the reaction systems, the forces observed in the first two tests (1956-1957 and 1957-1958) are believed to be below the maximum forces which might have been generated on the pipe piles by the seasonal freezing of the active layer. For example, in the 1956-1957 test, the support piles moved about 1.5 in. (Fig. 16), and excessive deflection occurred in the reaction beam; thus the maximum heave force of 25,000 lb on 21 November 1956 (Fig. 16) is considered to be less than the potential maximum force.

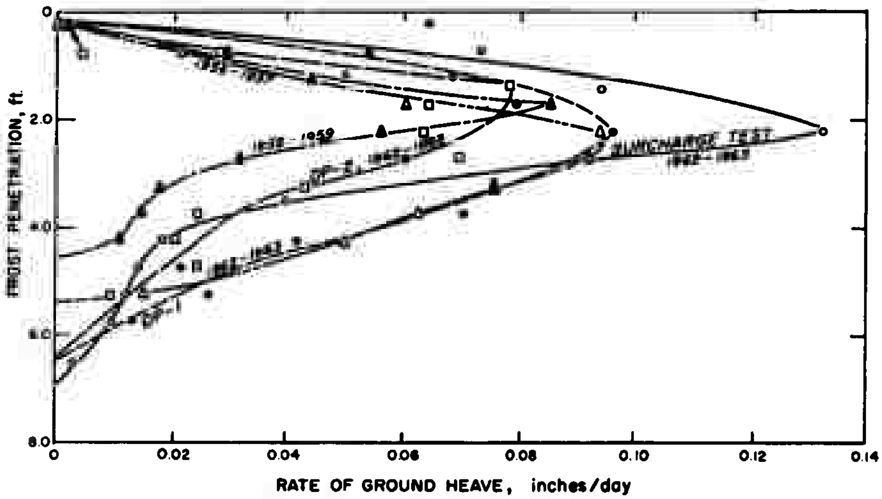

Figure 21. Rate of ground heave vs frost penetration.

The support piles, B-18 and B-19, had been loaded to failure in extraction tests conducted prior to this installation. Based on knowledge obtained since 1956 (Crory, in prep), it is now known that once the adfreeze bond between a pile and frozen ground is broken, the bond does not normally regain its original strength. Based on this knowledge the unit adfreeze bond strength developed between the permafrost and the piles, B-18 and B-19, could not withstand the excessive heave thrust imposed during the test. The support piles were not cased in the active layer; therefore, the force on each was the sum of the total heave thrust generated by the active layer plus one-half the heave force on the test pile, or 1.5 times the normal heave force.

In the 1957-1958 test, the heave and the heave force were well below the expected magnitudes. As pointed out earlier, the ground was exceptionally dry following the drought of the 1957 summer and insufficient moisture above the top of permafrost was available for normal ice lens formation. However, the results of the test do indicate that a considerable heave force can be generated without excessive ground heave. Although the ground heave was less than 0.5 in. total (assuming ground heave was that of the dummy pile) the maximum heave thrust recorded on the 8-in. pipe test pile was 25,000 lb. This force, reacting against the stable loaded platform, was essentially constant from 10 December 1957 until 10 April 1958.

The results of the 1958-1959 test on the creosoted timber pile appeared to be more reliable and more representative than the previous pipe pile tests. The reaction method used was successful in restraining the movement of the test pile to less than 0.2 in. The peak heave force observed during November 1958 (12,000 lb) during freezeback of the seasonal thaw zone is attributed to the difference in the unit adfreeze bond strength between soil and steel and between soil and a thick layer of creosote. The surface area per foot of the creosoted timber pile was approximately 1.5 times greater than that of the 8-in. pipe piles. The timber test pile was installed to the bottom of the surface thaw layer as it existed on 13 August

1958. Additional thawing after that date, of approximately 1 ft, permitted direct frost action on the bottom or base of the pile, after the first week in December, as shown in Figure 18. This was the period of maximum heave force (16,500 lb). Heaving of both the dummy and test piles ceased by 1 January 1959, with the penetration of the 30F isotherm into the permafrost.

During each of these studies, heave force observations were terminated shortly after thaw penetration began in the spring and complete relaxation of heave forces had not taken place.

In the 1962-1963 tests, in which both 8-in. steel pipe and creosoted timber piles were tested, the maximum heave forces observed were considered greater than observed in the previous tests (55,800 for steel and 35,600 for timber). Distinct fluctuations were observed in the heave force curves for both the timber and pipe piles. The peaks or maximum points of these fluctuations appeared a few days after a decrease in air and ground temperatures. The valleys or low points of the heave force curves appeared just after warming trends in air temperatures and had a distinct time lag with depth, as observed in the cooling periods. Similar fluctuations had been noted in the previous tests. They were also observed in tests conducted by Kinoshita and Ono (1963) and the decrease in heave force was inferred to be due to a relaxation phenomenon.

As mentioned earlier, the depth of the active layer was considered to be deeper than the 6.5-ft depth assumed at the time of installation. The increased depth of thaw immediately around the test pile was, in part, caused by the introduction of the slurry backfill, which, at the prevailing heat capacity of the permafrost near the top of the original permafrost table, could not freeze back. The permafrost temperatures along the entire length of the anchor piles were also relatively warm or marginal (31.0 to 32.0F). In addition to the possibility of some sections of the anchor piles being surrounded by unfrozen soil (slurry), it is considered probable that some creep of the anchor piles occurred, especially under the high loads observed on the proving ring, at temperatures only slightly below freezing. Progressive movement of the anchor piles is indicated by the fact that there was permanent movement of each test pile at the end of the test. Had no creep of the anchor piles occurred, all of the vertical movement of the test piles should have been produced only by the deflection of the proving ring and the elastic elongation of the steel rods and piles under load. These movements would have totalled less than 0.04 in. per 10-kip load. However, there was approximately 0.5 in. of permanent movement of the pipe pile and 0.2 in. of movement of the timber pile remaining at the end of the test, indicating some movement of the anchor piles.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of these field investigations indicate that for the types and sizes of piles used the heaving forces generated on piling during the seasonal freezing of frost susceptible soils may attain, or even surpass, 50,000 lb for the reported test conditions. Under normal field conditions such forces could in many cases exceed the load capacity of the pile through adfreeze bond and the imposed pile load, resulting in substantial annual displacement.

It also is concluded that for conditions such as represented by these tests the maximum rate of heave occurs early in the winter months, at relatively shallow depths (2-3 ft) and that the maximum pile heave force occurs during periods of active frost penetration with very cold near-surface ground temperatures. Relatively high or near maximum heave forces were also produced after complete freezeback of the seasonal thaw zone during periods of extreme cold.

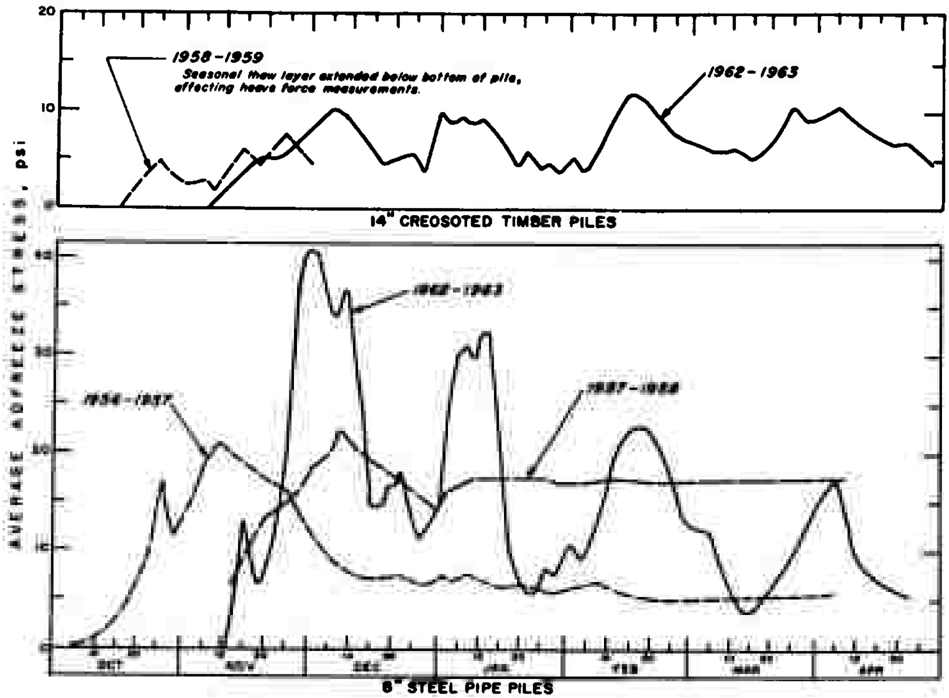

Figure 22. Average adfreeze stress vs time.

Based on the 1958-1959 and 1962-1963 tests, in which larger heave forces were registered on the pipe piles than on the larger timber piles, it is concluded that for the range of pile sizes employed the effective unit adfreeze bond of the active layer is more dependent on surface conditions (creosote) than on relative surface areas. As shown in Figure 22, the maximum unit adfreeze bond in the 1962-1963 test was about 41 psi for the steel pipe pile and 12 psi for the creosoted timber pile. Similar conclusions regarding the adfreeze strength potential of creosoted piles have been reached in the pile site C tests (Crory, in prep).

Recommendations

It is recommended that additional laboratory and field studies be conducted to augment the findings reported herein and provide additional information, especially on the relative heave forces generated on piles with various surface coatings under different soil, moisture and permafrost conditions.

Supplemental studies should be initiated on the effects of amount and distribution of moisture with depth, before and during the freezing period, preferably by non-destructive techniques. Continuous records of air temperature and frequent ground temperature observations should be obtained at all test locations to establish a relationship between air (ground) temperatures and intensity of frost heave.

Although the observations taken during the 1956-1957 test to determine the magnitude of differential ground surface heave caused by a restrained pile showed no detectable deflections, additional investigations of the radial surface deflection should be undertaken, using more accurate instrumentation.

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13. ABSTRACT

Studies were conducted at Fairbanks, Alaska, to measure the magnitude of heave force on piles and distribution of stresses in piles during frost penetration. This report summarizes the results of frost heave force measurements on creosoted timber and steel pipe piles during the period 1956-1959 and during the 1962-1963 freezing season. The results indicate that, for the types and sizes of piles used, the heaving forces generated on piling during the seasonal freezing of frost susceptible soils may attain, or even surpass, 50,000 lb. It is also concluded that for conditions represented by these tests the maximum rate of heave occurs early in the winter months at relatively shallow depths (2-3 ft), and that the maximum pile heave force occurs during periods of active frost penetration with very cold near-surface ground temperatures. Near maximum heave forces were also produced after complete freezeback of the seasonal thaw zone during periods of extreme cold.

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